CONODONTS FROM THE WOMBAT CREEK GROUP AND "WIBENDUCK LIMESTONE" (SILURIAN) OF EASTERN VICTORIA

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J.A. TALENT, A.J. SIMPSON, P.D. MOLLOY & R. MAWSON, R., 2005. Conodonts from the Wombat Creek Group and "Wibenduck Limestone" (Silurian) of eastern Victoria. *Proceedings of the Royal Society of Victoria* 115 (1): 265–291 ISSN 0035-9211.

Conodonts from four carbonate occurrences in the Wombat Creek Group — of the Wombat Creek Graben — a unit closely associated with the "type locality" of the inferred Benambran Orogeny, demonstrate that it includes horizons at least as old as *celloni* Zone (Early Silurian, late Llandovery, Telychian) as well as latest Silurian (Přídolí). Two and possibly three of the most prominent Wombat Creek Group limestones align chronologically with two of the oldest carbonate intervals of the Enano Group (of the Limestone Creek Half-graben) farther east in Victoria, specifically the Lobelia and Farquhar limestones. They also align chronologically with portion of the McCarty's limestone on the right flank of the Indi (= upper Murray) River in southeast New South Wales. The last of these documents carbonate sedimentation commencing earlier, in the early Llandovery (Rhuddanian). The youngest of the four Wombat Creek Group carbonate occurrences to have produced conodonts, Pyle's limestone deposit, is tectonically problematic, but its age is Přídolí (latest Silurian). The Wombat Creek Group and Enano Group sedimentation (and flanking "lost" carbonate platform accumulations) thus appear to have extended through most of Silurian time, from Llandovery to somewhere close to the Silurian–Devonian boundary. The Silurian sedimentary packages of the Wombat Creek Graben and Limestone Creek Half-graben have been regarded as developmentally discrete, but salient similarities in depositional sequence and in chronologic alignments are consistent with them being now-disjunct portions of a formerly continuous sedimentary accumulation, i.e. their preservation in separate tracts may be an artifact of post-depositional tectonics.

Conodont data from an isolated occurrence, the "Wibenduck Limestone", indicate probable mid-Ludlow age (probable latest Gorstian to earliest Ludfordian). It consists of limestone clasts and olistoliths and possibly equates with submarine fans of Lochkovian age elsewhere, such as the Sharpeningstone Conglomerate of the Yass area, southern New South Wales.

Keywords: Victoria, Silurian, Wombat Creek Group, Enano Group, "Wibenduck Limestone", conodonts, Benambran Orogeny

LIMESTONES, long regarded as Late Silurian in age, occur at many horizons in the Wombat Creek Group, a unit outcropping in the valley of the Mitta Mitta River and adjacent parts of the watersheds of the Gibbo River and of the Wombat and Morass Creeks of eastern Victoria (Stirling 1887, 1888b; Ferguson 1899; Chapman 1912; Thomas 1954; Whitelaw 1954; Talent 1959; Bolger 1982; VandenBerg et al. 1998a, 2000). Rocks of broadly similar age, known as the Enano Group, outcrop in the watersheds of the Indi, upper Buchan and upper Tambo rivers about 40–50 km farther east (Whitelaw 1954; VandenBerg et al. 1984; Allen 1987, 1988, 1991, 1992; Simpson & Talent 1995, 1996; Talent et al. 2003a) — for broad location see lower part of Fig. 1. It has been demonstrated (Simpson & Talent 1995) that the age-spectrum represented by the limestones and other calcareous sediments of the Enano Group equate with most of Silurian time — Llandovery (Aeronian and possibly late Rhuddanian) to Přídolí. Despite the abundance of limestone bodies in the Wombat Creek Group, no compelling data have been presented as to the age-spectrum represented by carbonate bodies and calcareous intervals of the latter. In this report, we provide conodont data bearing on this lacuna.

Opinions diverge regarding the environments of deposition of the Wombat Creek and Enano Groups, some authors regarding all carbonate bodies and calcareous intervals to be allochthonous (VandenBerg et al., 2000), others (principally ourselves) opining that both allochthonous and essentially autochthonous carbonate occurrences are represented. Regardless of the viewpoint advocated, it should be emphasised that most exposures of carbonate bodies and calcareous intervals in both regions are poor, leading to uncertainty regarding relationships to nearby non-calcareous sediments of most but not all limestone occurrences.

The "Wibenduck Limestone", previously regarded as autochthonous (VandenBerg 1988; VandenBerg et al. 1992, 2000), is regarded as consisting of clasts and olistoliths of various carbonate lithologies, lithified before cannibalisation and subsequent deposition at the top of the Sardine Conglomerate fan deposit; its continued use as a discrete formation is not recommended. A probable latest Gorstian–earliest Ludfordian age is indicated for the "Wibenduck Limestone" materials (see below).

The age-span represented by the Wombat Creek Group has special relevance as regards the Benambran Orogeny as it occurs in what may be termed the "type area" for the latter (Andrews 1938; Browne 1947). But the previously available poor age-constraints on the Wombat Creek Group and, by extension, the onset of the Benambran orogenic event (or events) in that area has led some authors to propose that it is a senior synonym of the "Quidongan Orogeny" (Crook et al. 1973; Ramsay & VandenBerg 1986), an event based, incidentally, on a very local and arguably regionally insignificant unconformity (authors' observations) within the Silurian sequence at Quidong in southeastern New South Wales. The latter unconformity occurs between the Merriangah Siltstone (age determined by graptolites as lying between the late Llandovery *Monograptus crenulatus* and *M. crispus* zones), a distal flysch sequence, and the overlying Quidong Limestone. The precise time-slice within the Wenlock–Ludlow represented by the Quidong Limestone is presently under investigation by R. Parkes (pers. comm.). Of greater sedimentary-tectonic significance at Quidong, in our view, is the Tombong Beds — a thick proximal flysch sequence — resting with profound unconformity on the Late Ordovician Bombala Beds and passing upwards with decrease in arenites into the aforementioned late Llandovery Merriangah Siltstone.

Our observations at Quidong, we emphasise, do not preclude age- and sedimentary-tectonic inferences from unconformities and patterns of sedimentation in Llandovery–Wenlock sequences elsewhere in eastern Australia, but need to be taken into account in evaluating data bearing on "Benambran events" throughout eastern Australia, including resolving questions of diachronism — for which presently available data are far from adequate.

The question of the ages and allochthoneity or otherwise of the limestone bodies in the Mitta Mitta River–Gibbo River–Wombat Creek region (VandenBerg 1998a; VandenBerg et al. 2000) is relevant with regard to dating associated strata and for inferences regarding the time-span to be accorded the Benambran orogenic cycle/cycles in this, its "type locality". Accordingly, before and after filling of the Dartmouth Dam, we extensively sampled most of the major occurrences of limestones in the Wombat Creek Group, and undertook additional sampling of limestones in the Enano Group of the Limestone Creek Half-graben — in quest of data additional to what we presented earlier for the Enano Group (Simpson & Talent 1995) — as well as sampling of the "Wibenduck Limestone".

Below we present conodont data from three limestone occurrences in the Mitta Mitta River–Gibbo River–Wombat Creek area (numbered 1–3 on Fig. 2;), from the small occurrence known as Pyle's limestone deposit near Benambra, and from the "Wibenduck Limestone" farther east (Fig. 1 and 2; see Appendix for locality data), and discuss the age and environmental significance of these occurrences.

CONODONT FAUNAS AND AGES

1. "Lower Mitta" limestone (Loc. 1 — see Appendix)

Low diversity but chronologically interesting faunas were obtained from the "Lower Mitta" limestone on the right flank of the Mitta Mitta River (Table 1). *Ozarkodina cadiaensis* has been reported previously from only three locations in southeastern Australia. These are an unnamed subsurface limestone in the Cadia Mine area about 20 km southwest of Orange (PC 402 of Bischoff 1986; see also Packham et al. 1999), low in the Boree Creek Formation (B5 of Bischoff 1986) and the Lobelia limestone lens adjacent to the Reedy Creek Fault in eastern Victoria (Simpson & Talent 1995: fig. 4). From the associated fauna of PC 402, Bischoff argued that *O. cadiaensis* was restricted to the latest Llandovery to earliest Wenlock *amorphognathoides* Zone. Simpson & Talent (1995: 93) in discussing the age of the Lobelia limestone lens argued that the lower range of the taxon could possibly be construed as of *celloni* Zone age. This was based on unillustrated associated faunas low in the Boree Creek Formation tabulated by Bischoff (1986) as *Pterospathodus amorphognathoides* that could possibly be interpreted as pennate forms of *Pterospathodus celloni sensu* Männik & Aldridge (1989; see also Männik 1998). New data from the Boree Creek Formation of east-central New South Wales are likely to shed further light on the lower limit of the *amorphognathoides* Zone in this unit (Molloy in prep.), but from published data it is reasonable to construe the range of *O. cadiaensis* as broadly late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones. The taxon, incidentally, was noticeably absent in a recent report on the fauna of an *amorphognathoides* Zone carbonate unit in the Cadia region (Rickards et al. 2001). Simpson & Talent (1995: 142) have noted that this taxon appears to be ecologically constrained.

The occurrence of Pa elements of *Ozarkodina australensis*, an Sc element of the genus *Distomodus* herein interpreted as *D. staurognathoides*, and the coniform *Panderodus* taxa generally accord with a *celloni* to *amorphognathoides* zone age for the "Lower Mitta" limestone. This unit can therefore be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and it can be broadly correlated with both the Lobelia and Farquar limestones in the Limestone Creek region (Simpson & Talent 1995).

2. *Brammall Bluff, Gibbo River (Loc. 2 — see Appendix)*

The small conodont fauna recovered from this unit includes elements of the ubiquitous Early Silurian taxon *Distomodus staurognathoides* and the more chronologically restricted *Ozarkodina cadiaensis*. A late Llandovery to earliest Wenlock *celloni* and *amorphognathoides* zones age-range, broadly equivalent with the "Lower Mitta" limestone discussed above, is therefore indicated. A single element of the coniform taxon *Pseudobelodella silurica* was also recovered. Armstrong (1990: 111) records *P. silurica* from the Lafayette Bugt Formation of Greenland and suggests this monospecific genus is restricted to the upper *celloni* and *amorphognathoides* zones. This unit can therefore also be correlated with the upper parts of the lower Claire Creek limestone unit, the upper parts of the McCarty's limestone and broadly correlated with both the Lobelia and Farquar limestones (Simpson & Talent 1995).

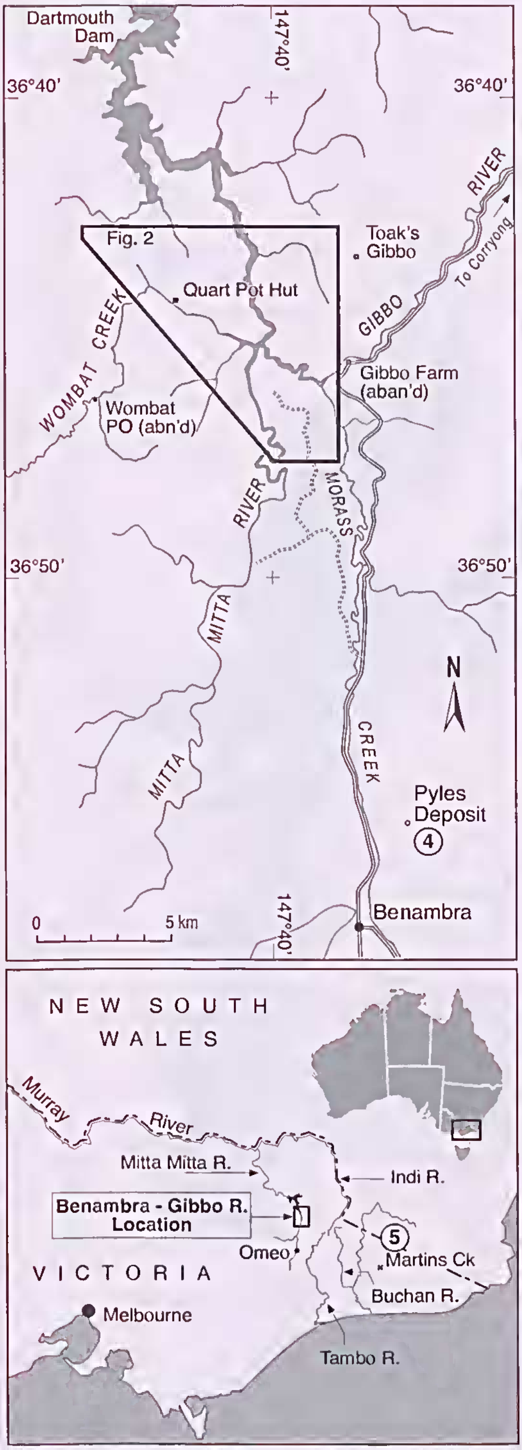


Fig. 1. Location of Fig. 2, and location of Mitta Mitta River-Gibbo River-Wombat Creek region in relation to eastern Victoria.

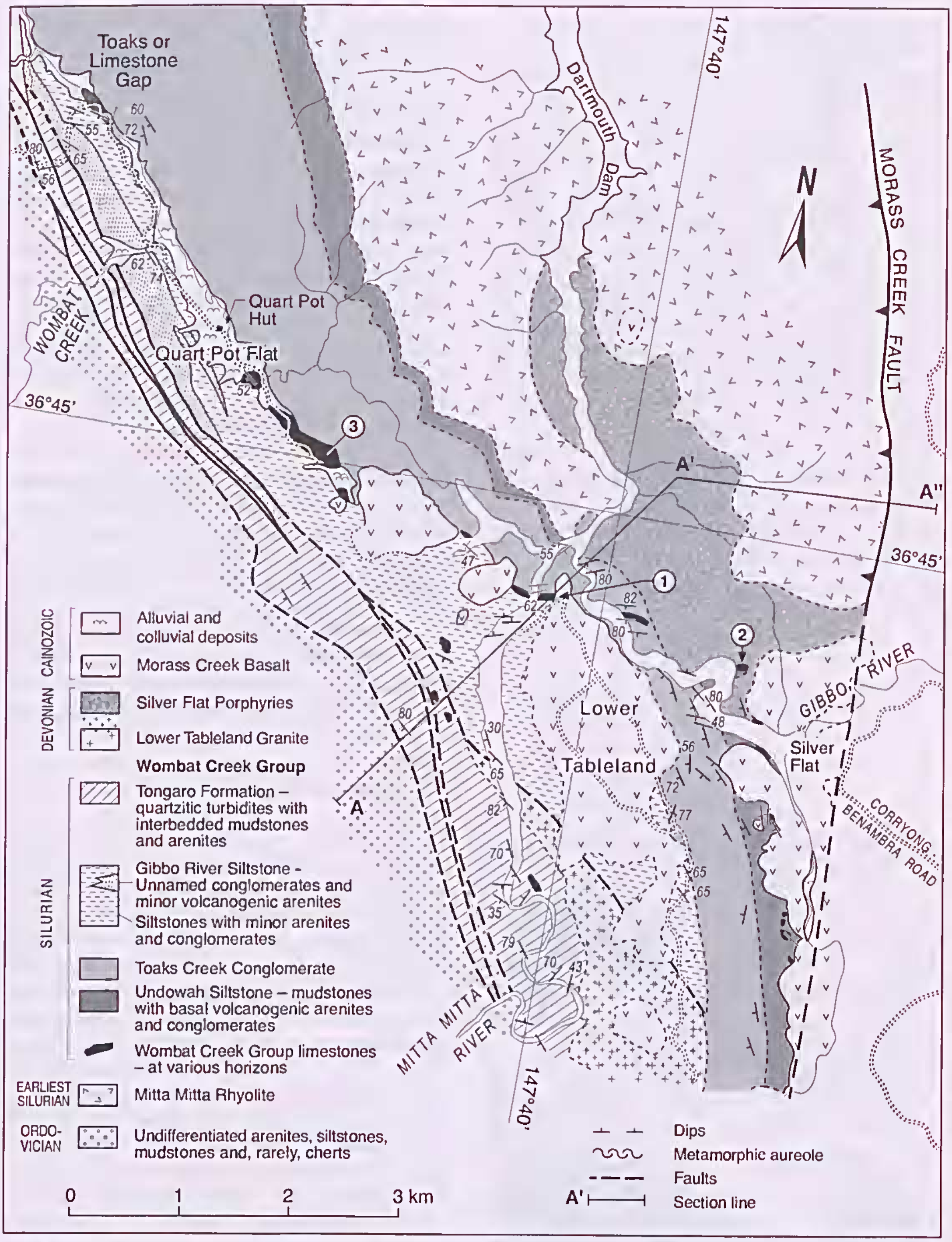


Fig. 2. Geology of Mitta Mitta River-Gibbo River-Wombat Creek region based on VandenBerg et al. (1998b). Localities 1, 2 and 3 refer to localities producing conodonts documented in his report — for details see appendix.

			Distamodus staurognathoides		*Ozarkodina eustrelensis*				*Ozarkodina cadiaensis*						*Ozarkodina* eff. *cadiaensis*			*Ozarkodina excavata excaveta*					*Ozarkodina martinssoni euriformis*	*Ozarkodina remsch. eosteinhornensis*	*Panderodus ? greenlandensis*	*Panderodus recurvetus*	*Panderodus ?* n.sp.	*Panderodus unicostetus*	*Panderodus* sp.	*Pseudobelodella silurice*	*Ozarkodina* sp.	*? Icriodus* sp. A	Totals
	SAMPLE	CAI	Pb		Pa	Pb	Sb	Sc	Pa	Pb	M	Sa	Sb	Sc	Pa	Pb	Sa	Pa	Pb	Sa	Sb	Sc	Pa	Pa							Sb	Sb	
1. "Lower Mitta ls."	0.0m																												1				1
	3.2m	6			6	2		1	2	1																		13	14				39
	4.9m	6																											1				1
	13.5m																									1		2	3				6
	14.5m																											4	3				7
	15.6m				2		1		1	2	2	1	1															4	5				19
	15,7m	6 - 6.5							3	2		1		1														11	5				23
	17.1m									1																		1	1				3
	18.3m					1																											1
	19.3m		1		1													1				2			1			1	7				14
	20.5m	6		1	1			1						1				2	1		1	2				3		9	13				35
	22.5m	6	1						8	5															5	1		19	22				61
	23.0m	6					1		1									1										3	5				11
	23.5m																											7	5				12
	27.4m	6							1	1		1						1				1			2	1		8	6				22
2.Brammall Bluff	0.1m	4.5 - 5	2	1					2	1	1																	1					8
	5.7m			1																						1			4	1			7
	11.2m																												2				2
	16.7m																					1				1							2
	67.0m	4.5 - 5																										1	3				4
3. Quart Pot SE		6.5 - 8													1	1	1																3
4. Pyles deposit		8																			1			1			1		2		1		6
5. "Wibenduck Ls."		5.5 - 6																	1	1		1	1									1	5
Totals			4	3	10	3	2	2	18	13	3	3	1	2	1	1	1	5	2	1	2	7	1	1	7	8	1	85	102	1	1	1	292

Table 1. Distribution and colour alteration indices (CAI values) of conodonts from samples from measured sections through the "Lower Mitta" and Brammall Bluff ("Hairpin") limestones, Gibbo R., and from spot samples from the Quart Pot and Pyle's limestones and the "Wibenduck Limestone". In the case of the Brammall Bluff section, the sampled section commenced 75 m upstream from the base of the carbonate-bearing sequence.

3. Quart Pot limestone (Loc. 3 — see Appendix)

Only four conodont elements were recovered from this unit. They are herein identified as elements of *Ozarkodina* aff. *cadiaensis*. It is therefore impossible to ascribe a reasonably accurate age for the deposition of this unit on available data. Given the stratigraphic context, however, a broad Early Silurian age is inferred.

4. Pyle's limestone deposit (loc. 4 — see Appendix)

Previous undocumented identifications of conodonts (Bischoff in Talent et al. 1975) implied the fauna is Přídolí or possibly Lochkovian in age (Simpson & Talent 1995: 82). This interpretation was based on a small number of form element taxa that could be interpreted as elements of *Ozarkodina remscheidensis* (Simpson & Talent 1995: 82). The identification in this study of a single Pa element as the subspecies *O. remscheidensis eosteinhornensis* restricts the age of the Pyle's deposit to the Silurian (latest Ludlow to mid Přídolí). This unit can be broadly correlated with the Native Dog limestone unit in the Limestone Creek region (Simpson & Talent 1995).

5. "Wibenduck Limestone" (Loc. 5 — see Appendix)

Conodonts reported but not documented from the "Winbenduck Limestone" (VandenBerg 1988: 131) were *Kockelella variabilis, K. ranuliformis, Ozarkodina confluens, O. excavata, Belodella anomalis*, and *Coryssognathus dubius* (recorded as *Pelekysgnathus dubius*). It has already been pointed out (Simpson 1995; Talent et al. 2003a) that *Kockelella ranuliformis* suggests a generalized Wenlock age, but may extend into the *Polygnathoides siluricus* Zone of the lower part of the upper Ludlow. *Kockelella variabilis* suggests *Ancoradella ploeckensis* and *Polygnathoides siluricus* zones, and *C. dubius* suggests the Ludlow. The fauna was thus thought to imply a generalized Ludlow age for the "Wibenduck Limestone" (Talent et al. 2003a). Lennart Jeppsson (pers. comm. 2003) has pointed out that on Gotland this association is restricted to a brief interval somewhere in the latest Gorstian–earliest Ludfordian.

It should be noted that none of the conodonts listed above have been examined by the authors. In this study only a small number of recognisable conodonts were recovered. These were elements of *Ozarkodina excavata excavata*, a single Pa element of *Ozarkodina martinssoni auriformis*, and a Pb element of *Icriodus* sp.

O. martinssoni auriformis has been obtained from the Coral Gardens Formation of the Jack Group in the Broken River region (Simpson 2000, 2003). The taxon is interpreted as ranging from the Ludlow *siluricus* Zone to the latest Přídolí to Early Devonian *woschmidti* zone. Simpson (1998) reported the recovery of icriodontid elements from the top of the *siluricus* Zone from two localities in the Broken River region.

On available data, the "now lost" source of this allochthonous material correlates broadly with the autochonous sequences spanning the upper parts of the upper Claire Creek limestone unit and interbedded carbonates and clastics directly overlying this unit in the Limestone Creek region (headwaters of the Indi River) (Simpson & Talent 1995). Because this fauna is from clasts of various lithologies, additional sampling could well produce minor chronological incongruities.

Conodont Colour Alteration Indices (CAI)

Determinations of CAI of the conodonts from this study (Table 1) have been made using a colour standard set of conodonts — of various shape, size and robustness — made available to us by Dr Anita Harris of the U.S. Geological Survey, thus obviating problems which might have arisen from inaccuracies in published colour illustrations (Epstein et al. 1977; Harris 1979 1981; Rejebian et al. 1987), or apparent differences in colour occasioned by relative robustness or delicacy of individual elements for which CAI values were being estimated.

Conodonts from four of the five localities investigated fall in the range of CAI 5.5–6 (Table 1), not very much above the overall average of 4.5–5.5 encountered over much of the Lachlan Foldbelt of eastern Australia for most Ordovician, Silurian and Devonian (early Givetian and older) platform sequences (Brime et al. 2003; Mawson & Talent unpub. data). Because the sequence at Bammall Bluff (loc. 2) had been reported to include skarn associated with felspar-quartz porphyry (VandenBerg et al. 1998a: 204), we anticipated that conodonts from this occurrence were likely to have high CAI values indicative of temperatures associated with skarns found adjacent to plutons (cf. Meinert 1992). Fluid inclusions, however, indicate prevailing

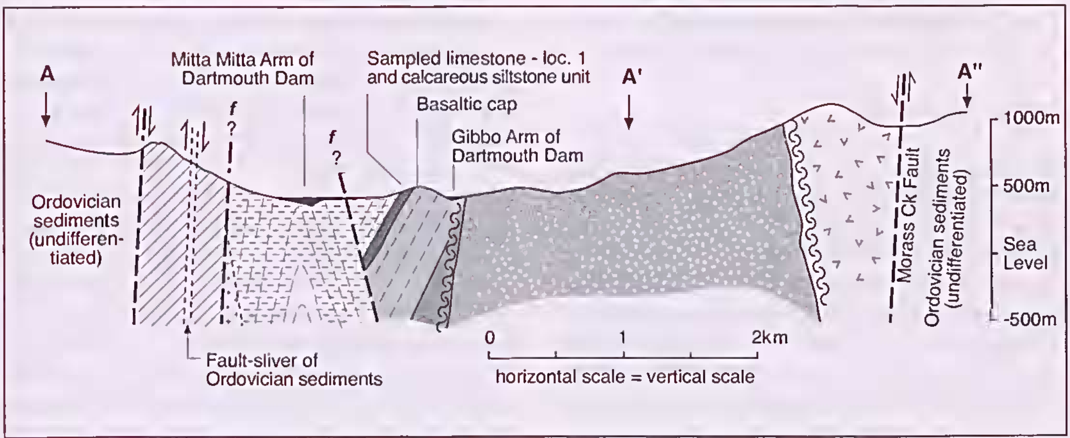


Fig. 3. Cross-section A-A'-A" of Mitta Mitta River-Gibbo River-Wombat Creek region (for location see Fig. 2).

temperatures of formation of skarns in the range 300–700°C, but with occasional lower and much higher temperatures. The CAI values of conodonts from the Brammall Bluff sequence (loc. 2) are 4.5–5. This equates with about 250–350°C for 1–10 Ma of annealing (cf. Epstein et al. 1977; Harris 1979, 1981; Rejebian et al. 1987) — towards the lower end of temperatures for formation of skarns.

Even in hand specimens, the calcareous rocks of the tiny Pyle's limestone occurrence (Fig. 1; loc 4) can be seen to be recrystallized (Whitelaw, 1954); the metamorphism is presumed to have been connected with the nearby Brothers Syenite. The conodonts are transparent, indicating CAI values around 8, and much higher annealing temperatures than for the four other occurrences considered here. Three small limestone occurrences on the western flank of Morass Creek about 1.5–2 km above its junction with the Gibbo River are reported to have undergone skarn formation (Fig. 2; Birch et al. 1995; VandenBerg et al. 1998a: 205, 1998b); these were not sampled.

EASTERN VICTORIAN SILURIAN LIMESTONES: ALLOCHTHONOUS, AUTOCHTHONOUS, OR AN ENVIRONMENTAL MEDLEY?

VandenBerg et al. (1998a, 2000: p. 89) have argued for allochthoneity of the Silurian limestones of the Wombat Creek and Enano Groups of eastern Victoria. They have suggested, with some reservations due to generally poor exposures, that the numerous limestone occurrences in these groups reflect carbonate accumulation on "lost" carbonate platforms (without terrigenous clastics) followed by displacement as olistoliths into deep-water contexts. Viewed this way, such limestones are taken to lack constraining age-significance for sequences in which they are now found. Llandovery and Wenlock ages indicated by conodont data from the Enano Group (notably Simpson & Talent 1995) and for the Wombat Creek Group (herein) are therefore to be discounted.

We accept that inferences as to autochthoneity or otherwise of most Cambrian–Pragian limestone occurrences in eastern Victoria should be approached with caution, especially in the absence of other palaeontological data — such as from graptolites or acritarchs — in the enclosing clastic sediments. Many such occurrences, long considered autochthonous, such as the Cambrian limestone-charged channel deposits and limestone olistoliths of the Dolodrook River (Talent et al. unpub. data), and the Early Devonian limestones of the Walhalla Synclinorium from Coopers Creek to Loyola (Mawson & Talent 1994) — the limestones of the Tyers-Boola area and minor parallel-bedded occurrences in the Wilson Creek Shale being the obvious exceptions — are indeed allochthonous, having been lithified prior to being dislodged and transported downslope. And we believe that at least some of the limestone occurrences in the Wombat Creek and Enano Groups are also allochthonous, but hesitate to assume all are allochthonous, and even more so that age-inferences from their faunas should be ignored — especially when shells were not broken or not even disarticulated before burial and lithification.

A. WOMBAT CREEK GRABEN (WOMBAT CREEK GROUP)

1. Mitta Mitta River

The elegant exposures now displayed as a result of erosion by waters of the Dartmouth Dam around the "Lower Mitta" limestone (VandenBerg et al. 1998a, 1998b) on the right and left flanks of the dam were a principal focus for the present investigation. Most attention was devoted to the right (eastern) flank of the dam (Loc. 1 in Appendix). Up-section, a gradual change from bedded to massively bedded limestone is followed by gradual change back through bedded limestones to interbedded, often crinoidal, limestones and mudstones. The overall upward decrease in calcareous content of the upper limestone-mudstone sequence is interpreted as reflecting a deepening event. The upper limestone-mudstone sequence seems also to reflect lack of lithification of some of the carbonate materials prior to reaching their final resting place, but this needs closer study. Retention of coherency of such a sequence during downslope transport seems unlikely, but we hesitate to reject the possibility that this limestone-clastic occurrence is olistolithic. We interpret the sequence as having probably accumulated *in situ*.

Upstream on the left bank of the Mitta Mitta River are intervals of conglomerate within the prevailing siltstone–arenite sequence with two small patches with loose chunks of white limestone or marble sluiced out by the waters of the Dartmouth Dam; these limestones have failed to produce conodonts and appear to have been allochthonous. The superbly exposed limestone and calcareous mudstone body (Whitelaw 1954: fig. 2^F; "Meanders 3" limestone lens of VandenBerg et al. 1998a) outcropping in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek was noted earlier. We view this occurrence, with prominent stylobrecciation, as probably autochthonous because of the wide range of lithologies, and the gradual transition from massive through bedded limestone to calcareous mudstones with limestone interbeds. In our view, it would have been difficult for such a sequence to retain stratigraphic coherence during major downslope displacement.

2. Gibbo River

We suspected that, because of association with conglomerates, the Gibbo River limestone occurrences mapped by Whitelaw (1954: figs. 3^A and 3^B) could be allochthonous. The Silver Flat limestone (Whitelaw 1954: fig. 3^B), outcropping poorly on both flanks of the Gibbo River, mostly rather marmorised and/or metamorphosed, and mainly covered by alluvials, could well be a large olistolith, 300 m or more in length, but possibly extending to the

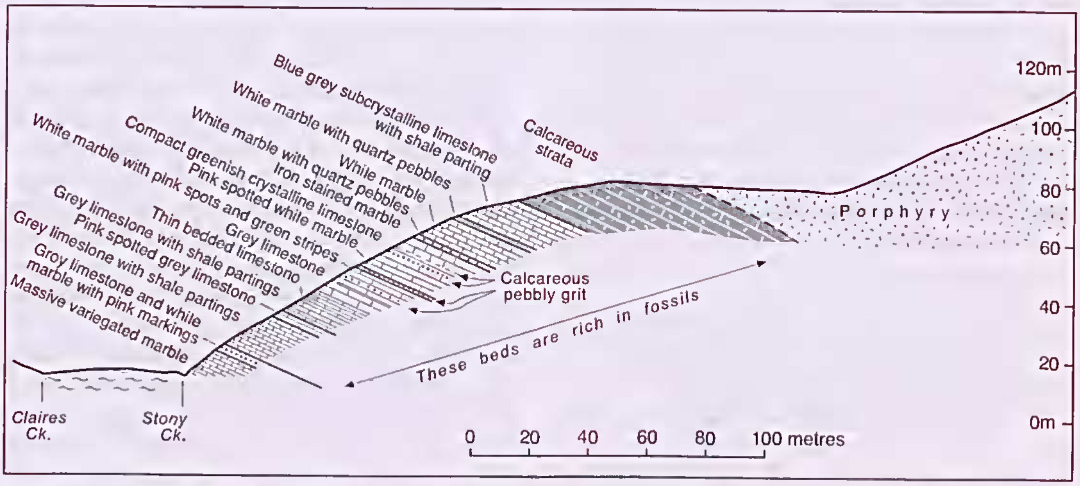


Fig. 4. H. S. Whitelaw's (1954: fig. 1) section, oriented northeast, crossing Claire and Stoney Creeks about 80 m downstream from Charles Summer's northern marble quarry; lithologies in this sequence, now viewed as portion of the Cowombat Siltstone, are according to Whitelaw; the porphyry is Snowy River Volcanics (Early Devonian). This sequence, but with not the same alignment, together with overlying and underlying strata was sampled (185 samples) for conodonts by Simpson & Talent (1995: text-figs 2, 6, 7) along their sections SC (in part), SCA and SCV.

south-southeast beneath Cainozoic basalt and colluvial cover for > 1,000 m in length. Sampling of this occurrence failed to produce conodonts.

We agree with VandenBerg et al. (1998a, 1998b) that their "Lower Gibbo [limestone] olistolith" (Whitelaw 1954: fig. 3^{A}) is almost certainly an allochthonous block, but wave-action by the Dartmouth Dam has not revealed contacts between this massive limestone/marble body and the nearby conglomerate and fossiliferous shales.

The Brammall Bluff occurrence (= Whitelaw 1954, Fig. 3^{B}; = "Hairpin limestone olistolith and skarn" of VandenBerg et al. 1998a, 1998b) is complex, consisting of massive, yellow-buff-weathering carbonate for the first c. 75 m of outcrop, stratigraphically above which (upstream), commencing at $5607_{96}59314_{63}$ on Benambra 1:50,000 topographic sheet 8424-3, the sequence becomes bedded with thin, irregular, rather bioclastic and nodular limestones (up to 2 cms thick) for about 37 m of outcrop. Eleven samples collected in this interval were acid-leached for conodonts. Farther upstream (for an additional c. 25 m) are yellow-buff-weathering carbonate blocks (to 5-m scale). These appear lithologically similar to the first 75 m of outcrop. They are not *in situ*, but appear to be olistoliths exhumed from the clastic sequence upslope, though none were noted within that sequence as presently exposed. We did not investigate the petrology of the yellow-buff-weathering carbonates, but were struck by the relatively good preservation of the fossils, mostly tabulate and rugose corals, occurring in isolation in matrix or in the thin beds of limestone within the clastic–cum–carbonate sequence. We accept that this tract has olistoliths (the yellow-buff-weathering carbonates), but suggest it also has beds of limestone apparently emplaced before lithification. Because of this we suggest that whatever palaeontologic information (mostly tabulate and rugose corals) can be derived from these limestones should not be dismissed in discussions of age of the associated strata.

Reconnaissance sampling of the "lower Gibbo" and Silver Flat occurrences failed to produce conodonts, but the sampled section through the Brammall Bluff occurrence (Loc. 2 — described above) produced sparse but useful faunas (Table 1). As indicated in the discussion of the conodont fauna above, it is possible to ascribe a relatively chronologically constrained time-interval to deposition of this sequence, and, as will be argued below, to infer broad synchroneity of Early Silurian carbonate deposition in the Wombat Creek Graben and the Limestone Creek Half-graben to the east.

3. Wombat Creek and Toak's Gap

Our sampling of the Toak's Gap outcrops has failed to produce conodonts on several occasions but one occurrence, at the southeast end of the Quart Pot limestone tract (Loc. 3), possibly a continuation of the Toak's Gap occurrence, has produced a faunule consisting of elements herein interpreted as *Ozarkodina* aff. *cadiaensis*.

4. Pyle's limestone deposit

Despite poor exposures, the parallel bedding of the thin limestones we collected and acid-leached leads us to believe this occurrence is autochthonous. VandenBerg et al. (1998a) suggest that the Pyle's occurrence may be a tiny erosional remnant of limestone deposits that were much more extensive during Silurian times. They referred the Pyle's occurrence to the Undowah Mudstone, the oldest unit of the Wombat Creek Group. If this stratigraphic allocation is accepted, and the late-Ludlow–Přídolí age we attribute to this occurrence is also accepted, all or virtually all of the post-Undowah units of the Wombat Creek Group would be Devonian in age! We suggest, however, that this isolated occurrence is Gibbo River Siltstone, or possibly a younger unit of the Wombat Creek Group not represented in the main outcrop area of Wombat Creek Group (Fig. 2).

Our experience in investigating conodont faunas from allochthonous carbonate bodies — e.g., the Walhalla Synclinorium of eastern Victoria (Mawson & Talent 1994), the Broken River region of northeastern Queensland (Sloan et al. 1995; Talent et al. 2003b) and the eastern flank of the Hill End Trough and the Tamworth Belt of New South Wales (Mawson et al. 1998; Talent & Mawson 1999) — indicates a high proportion of allochthonous carbonates in debris-flows have ages very little different from the age of the enclosing matrix, with a tendency to decrease in age up-sequence — as was demonstrated for the eastern flank of the Hill End Trough (Talent & Mawson 1999). Age-data from a single clast or olistolith may be problematic due to possibilities of platform collapse and downslope transport of olistoliths and smaller debris detached from deep within platform sequences. Dissection of carbonate platforms upslope may, moreover, lead to increasing proportions of older clasts up-sequence, as was encountered with the carbonate clasts of the Thatch Creek section of the Perry Creek Formation of northeastern Queensland (Sloan et al. 1995). We believe, nevertheless, that "clast ages", judiciously evaluated, may be valuable where unequivocally autochthonous limestone horizons appear to be lacking.

5. *Summary*

We have found no compelling evidence for <u>all</u> limestone occurrences in the Wombat Creek Group being allochthonous or, alternatively, all autochthonous. We suggest that some of the Wombat Creek Group limestone occurrences are most likely allochthonous, but others appear to be autochthonous. The Brammall Bluff occurrence (Loc. 2) we suggest is substantially allochthonous, but portions of the sequence — because of thin, parallel-bedded limestones, interpreted as having been lithified subsequent to deposition — are believed to be largely if not entirely autochthonous, and conodonts from them (Table 1) constrain the age of the strata with which they are interleaved. The majority of other limestone occurrences in the Wombat Creek Group — with outcrops not allowing resolution of relationships to nearby clastics — are best categorised as suspect.

B. LIMESTONE CREEK HALF-GRABEN (ENANO GROUP)

Prior to our sampling of various sequences in the northern part of the Limestone Creek Half-graben, all carbonates in the region had been accorded a generalised Late Silurian age (e.g., VandenBerg 1988; Walley et al. 1990). Our sampling of numerous carbonate intervals in this region revealed a much broader spectrum of ages: from early Llandovery to Přídolí *eosteinhornensis* Zone (Simpson & Talent 1995; Talent et al. 2003a). Subsequently, VandenBerg et al. (1998a, 2000) suggested that the limestone occurrences in the Enano Group, cropping out in the headwaters of the Indi, Buchan and Tambo Rivers, may be allochthonous and that palaeontologic data derived from them by us (Simpson & Talent 1995) may not be compelling for dating associated strata. As this suggestion has implications for the tectonic scenario presented by VandenBerg and his colleagues, we dwell a little on the question of allochthoneity *versus* autochthoneity of the carbonate units for which we have previously presented conodont data.

Our sparse conodont data from the McCarty's limestone lens (Simpson & Talent 1995: text-fig 3A) are biostratigraphically consistent with it being a stratigraphically coherent body. It has produced the oldest conodont assemblages (early Llandovery, Rhuddanian) so far obtained from the region. Whether or not it is a fault-bounded body, autochthonous, or a large olistolith cannot be determined because of the absence of exposures displaying relationships of the limestone to nearby clastics.

Because of its well-bedded character, we are disinclined to accept an allochthonous interpretation for the highly fossiliferous Lobelia limestone lens (Simpson & Talent 1995: text-fig. 4) of the Reedy Creek area; it has produced conodonts indicative of the late Llandovery–earliest Wenlock *celloni–amorphognathoides* interval. The Farquhar limestone lens, about 1.5 km along strike from the Lobelia lens, is conspicuously more massive and more recrystallized than the latter. It could be allochthonous but, because it is the same age as the Lobelia lens and located more or less on strike with the latter, we are not inclined towards an allochthonous interpretation for this limestone lens, but such is indeed possible. Unequivocal answers might be possible from a minimum of trenching across strike of the boundaries of these two occurrences.

The Claire Creek–Stoney Creek outcrop-tract, in the central parts of the region, consists of two main limestone units separated by a pelitic sequence with subordinate carbonates, followed by a sequence with generally decreasing ratio of carbonate to clastics. In an earlier phase of nomenclatorial zeal (Talent et al. 1975), the entire package was referred to — in line with recommendations of the then code of stratigraphic nomenclature, to emphasize prominent or dominant lithologies — as the Claire Creek Limestone Member. Though this section was heavily sampled (367 samples) over a distance of 1.4 km (Simpson & Talent 1995, text-figs. 2, 6, 7, tables 2–5), it displays no inconsistencies in conodont biostratigraphy. VandenBerg (unpub. ms.) however challenged this, pointing out an overlap of two index taxa (*A. ploeckensis* and *O. sagitta*), previously thought to be chronologically separate, in the lower part of the upper Claire Creek limestone unit. This we regard as trivial, with no bearing on the regional synthesis previously presented (Simpson & Talent 1995).

Despite metamorphism to lower greenschist facies and poor yields of conodonts, particularly for the lower limestone unit, data are sufficient to indicate deposition through a large slice of Silurian time (cf. Table 2; Simpson & Talent 1995). Near basal samples of the lower limestone unit have produced a tentatively identified taxon *Ozarkodina aldridgei* that suggests an earliest possible age of middle Aeronian (Simpson & Talent 1995). The higher intervals of the lower limestone unit have produced poor faunas typical of the late Llandovery to early Wenlock *celloni* and *amorphognathoides* zones. Equivocal fragmentary specimens from near the top of the lower unit suggest that, like the McCarty's limestone lens, the lower limestone unit may extend into the "post-*amorphognathoides*" interval of the Wenlock. The lower intervals of the "upper limestone unit" (cf. fig. 5) are typified by taxa indicative of a broad Wenlock age. Higher in the unit, there is an overlap of the zonal index species of the typically European Wenlock *sagitta* Zone with the first appearance of zonal index species of the cosmopolitan Ludlow *ploeckensis* Zone. We regard this apparent biostratigraphic disparity as being inconsequential.

The identification of the single specimen of *O. saggita* has been questioned by Corradini & Serpagli (1999). One of us (AS) has subsequently had the opportunity to compare the specimen with topotype material of *O. saggita* from Europe and must agree that the original identification is equivocal. More sampling is required to resolve the issue. Should the interpretation of Corradini & Serpagli (1999) prove correct, this implies resumption of carbonate sedimentation in the Limestone Creek region in the early Ludlow rather than the late Wenlock. It would also remove any scintilla of biostratigraphic dissonance that could possibly be construed as supporting evidence for an allochthonous origin.

Faunas above this level, high in the "upper limestone unit", are typically Ludlow in aspect (Simpson & Talent 1995). Constrained by data from the overlying and underlying limestone units, the intervening pelitic sequence is therefore inferred to be broadly Wenlock in age. Intermittent carbonates in the predominantly clastic sequence overlying the "upper limestone" interval also yield broadly Ludlow faunas. Despite the lack of index species, this latter sequence is thought to extend well into the later Ludlow.

In our earlier sampling (Simpson & Talent 1995) we gave special attention to the Claire Creek–Stoney Creek sequence because of the exceptional length of the sequence, and the lengthy intervals of excellent exposure. The diverse lithologies are indicated in a cross-section by Whitelaw (1954, section A, redrawn as Fig. 4 herein). From our experience, such lithologically diverse and generally thin-bedded sequences characterized by a broad spectrum of lithologies and contrasting competence — with a significant proportion of mudrocks — would have been prone to disintegration during major downslope movement. Moreover, brachiopods from the various lithologies in this section, admittedly not abundant, are overwhelmingly articulated. Though conceivable, this is not what would be anticipated if the unlithified sediments had undergone substantial downslope transport as olistostromes. We are therefore inclined to view this, the most important Cowombat Siltstone sequence, as autochthonous. We accordingly accept the conodont data obtained from it as indicating true ages for the sequence as a whole — i.e. from mid-Aeronian (mid-Llandovery) to the late Gorstian (Early Ludlow) *ploeckensis* Zone, probably extending into the Ludfordian (late Ludlow) — and not depositional ages: somewhere on an adjacent platform prior to being dislodged and deposited in basinal contexts.

The largest tract of Silurian limestone in the valley of Limestone Creek, extending for approximately 2 km from Jim Spean Creek (Kimberley Hut area) through the Pendergast's Cave and Sheehan's Bluff areas (Whitelaw 1954, fig. 1^{C}), may be interpreted as a single autochthonous or allochthonous slab or, because of a substantial tract of alluvials and older terrace gravels about Painter Creek, interpreted as possibly two large olistoliths. We incline to the former interpretation but, because of poor exposures of the nearby clastics and absence of exposures displaying contacts between the limestones and clastics, the nature of this body (or bodies) cannot be compellingly demonstrated. The age of this body (or bodies) is uncertain. No conodonts were obtained from a section sampled across strike through Sheehan's Bluff, but a few poorly preserved and chronologically inconsequential *Panderodus* obtained from samples from a section approximately 600 m along strike north of Sheehan's Bluff give hope that additional sampling may eventually provide chronologically useful data.

Among limestone occurrences only cursorily examined and sampled by us are some which have parallel-bedded and occasionally bioclastic limestones, e.g. the Philip's Bluff and Little Stoney

Creek occurrences (Whitelaw 1954: fig. 1^B); these we believe are probably autochthonous. Like the Sheehan's Bluff section (see above), these have produced only a few poorly preserved *Panderodus*. Others, such as those on the western flank of Limestone Creek in the northern part of Whitelaw's fig 1^C are parallel-bedded and interbedded with clastics; these limestones appear to be autochthonous but could be allodapic. We suspect that the body through which we sampled our section LC (Simpson & Talent 1995: upper part of text-fig. 2; table 1) with, inter alia *Ozarkodina australensis*, may be allochthonous, but there is an absence of exposures displaying relationships of the limestone to nearby clastics.

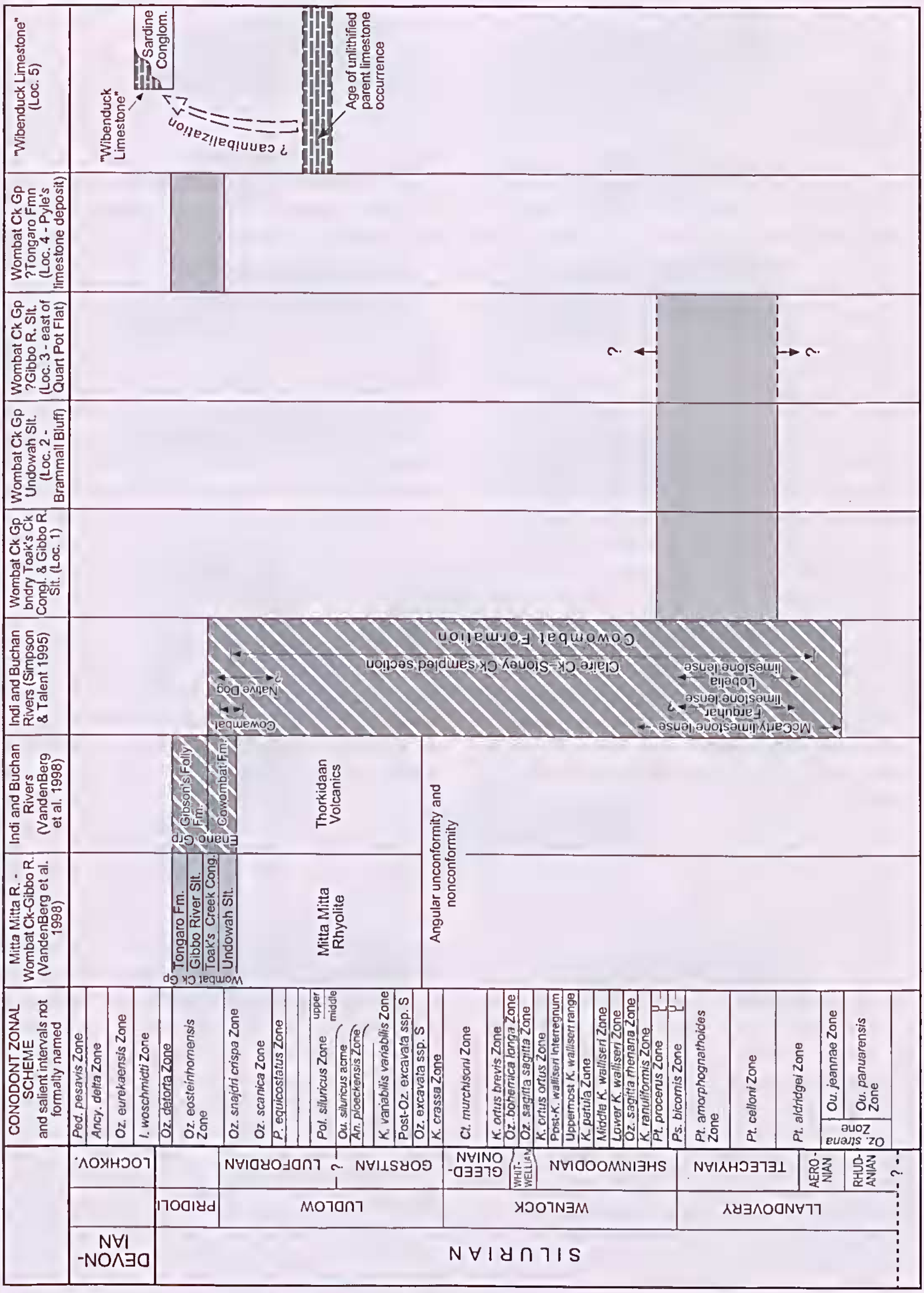
The occurrences in the valley of Annabella Creek and adjacent parts of Limestone Creek (Whitelaw 1954, fig. 1^A) appear to be allochthonous. These and limestones intimately associated with acid and intermediate volcanics, volcanic breccias and greywackes farther south in the vicinity of the Wilga and Currawong prospects (Allen 1991) appear also to be allochthonous, but these occurrences need to be cautiously probed for relationships in the field and from the large corpus of bore cores available at the Benambra Mine. At least one limestone occurrence in this area, outcropping on and adjacent to the Teapot Track Creek in the vicinity of 837_0080_9, consists of limestone clasts and is therefore unequivocally allochthonous. This occurrence failed to produce conodonts.

An isolated limestone lens among richly fossiliferous calcareous mudstones at Cowombat Plain has yielded late Ludlow *crispa* Zone conodonts (Simpson et al. 1993). The interval of fine clastics above this lens, exposed in Native Trout Creek, is therefore most probably Přídolí in age. Conodonts from limestones associated with clastics at Native Dog Plain are generalised Late Silurian associations, but high in the sequence are faunas typical of the Přídolí *eosteinhornensis* Zone. The range-base of the name-giving taxon predates the Ludlow–Přídolí boundary in many parts of the world (Aldridge & Schönlaub 1989). However that may be, the occurrence at Native Dog Plain seems to be the youngest preserved horizon in the tracts of Silurian rocks outcropping in the headwaters of the Indi, Buchan and Tambo Rivers. These sequences extend the age-spectrum for the Cowombat Formation to higher horizons than those encountered in the Stoney Creek–Claire Creek sequence. The massive limestone in the lower part of the Native Dog sequence aside, these sequences are shaley with minor limestones, not the sort of sequences we would anticipate likely to retain coherence during grand-scale downslope movement.

In summary, though we earlier noted that the Enano Group included allochthonous limestones (Conaghan et al. 1976: 529, as Cowombat Group), we did not view all limestone occurrences in that unit, nor, for instance at Tyers River and Tamworth areas cited in the same paragraph, to be exclusively allochthonous, though, regrettably, this was not unequivocally asserted. Our subsequent sampling of the Enano Group and Wombat Creek Group have produced no compelling evidence for all limestone occurrences in the two regions to be exclusively either allochthonous or autochthonous. We accept that some of the limestone occurrences in both regions are allochthonous, but others (possibly a minority) appear to be autochthonous and therefore of value in dating the enclosing sediments. Others, where outcrops do not allow resolution of relationships to nearby clastics, are best categorised as suspect until additional data become available.

We draw attention to the profound influence of faulting in preservation of the Silurian sequences in the Wombat Creek Graben and Limestone Creek Half-graben, and see no reason why these fault boundaries have any necessary relationship to the former boundaries of the sedimentary "basin" (or "basins") in which these sedimentary packages accumulated. Similarities, admittedly very broad, in depositional sequence and in chronologic alignments between the two regions suggest that the sequences in the two regions may be viewed as possibly now-disjunct portions of a formerly continuous sedimentary pile. In other words, their preservation in now separate tracts may be an artifact of post-depositional tectonics.

Table 2. Silurian correlations advocated on the basis of conodont data presented here and by Simpson et al. (1993) and Simpson & Talent (1995, 1996), compared with correlations suggested by VandenBerg et al. (1984–1999, principally 1998a). Scale on the left is based on Zhang & Barnes (2002) for the Llandovery, Jeppsson (1997c) and Calner & Jeppsson (2003) for the Wenlock, and Jeppsson (in Eriksson 2001) for the Ludlow and Přídolí. Abbreviations for generic names in the conodont zones are as follows: *An.* = *Ancoradella*, *Ancy.* = *Ancyrodelloides*, *Ct.* = *Ctenognathodus*, *I.* = *Icriodus*, *K.* = *Kockelella*, *Oz.* = *Ozarkodina*, *Ou.* = *Oulodus*, *Ped.* = *Pedavis*, *Pol.* = *Polygnathoides*, *Ps.* = *Pseudooneotodus*, *Pt* = *Pterospathodus*.


CONODONT ZONAL SCHEME and salient intervals not formally named
Mitta Mitta R. - Wombat Ck-Gibbo R. (VandenBerg et al. 1998)
Indi and Buchan Rivers (VandenBerg et al. 1998)
Indi and Buchan Rivers (Simpson & Talent 1995)
Wombat Ck Gp bndry Toak's Ck Congl. & Gibbo R. Slt. (Loc. 1)
Wombat Ck Gp Undowah Slt. (Loc. 2 - Brammall Bluff)
Wombat Ck Gp ?Gibbo R. Slt. (Loc. 3 - east of Quart Pot Flat)
Wombat Ck Gp ?Tongaro Fmn (Loc. 4 - Pyle's limestone deposit)
"Wibenduck Limestone" (Loc. 5)
DEVONIAN
SILURIAN
LOCHKOV.
PRIDOLI
LUDLOW
WENLOCK
LLANDOVERY
LUDFORDIAN
?
GORSTIAN
GLEEDONIAN
WHITWELLIAN
SHEINWOODIAN
TELYCHIAN
AERONIAN
RHUDDANIAN
?
Ped. pesavis Zone
Ancy. delta Zone
Oz. eurekaensis Zone
I. woschmidti Zone
Oz. detorta Zone
Oz. eosteinhornensis Zone
Oz. snajdri crispa Zone
Oz. scanica Zone
P. equicostatus Zone
Pol. siluricus Zone
upper
middle
Ou. siluricus acme
An. ploeckensis Zone
K. variabilis variabilis Zone
Post-Oz. excavata ssp. S
Oz. excavata ssp. S
K. crassa Zone
Ct. murchisoni Zone
K. ortus brevis Zone
Oz. bohemica longa Zone
Oz. sagitta sagitta Zone
K. ortus ortus Zone
Post-K. walliseri Interregnum
Uppermost K. walliseri range
K. patula Zone
Middle K. walliseri Zone
Lower K. walliseri Zone
Oz. sagitta rhenana Zone
K. ranuliformis Zone
Pt. procerus Zone
Ps. bicornis Zone
Pt. amorphognathoides Zone
Pt. celloni Zone
Pt. aldridgei Zone
Ou. jeannae Zone
Oz. strena Zone
Ou. panuarensis Zone
Wombat Ck Gp
Tongaro Fm.
Gibbo River Slt.
Toak's Creek Cong.
Undowah Slt.
Mitta Mitta Rhyolite
Angular unconformity and nonconformity
Enano Grp
Gibson's Folly Fm.
Cowombat Fm.
Thorkidaan Volcanics
Cowombat
Native Dog
?
Claire Ck - Stoney Ck sampled section
Cowombat Formation
Farquhar limestone lense
Lobelia limestone lense
McCarty limestone lense
?
?
?
"Wibenduck Limestone"
Sardine Conglom.
? cannibalization
Age of unlithified parent limestone occurrence

C. SARDINE CREEK ("WIBENDUCK LIMESTONE")

A tract of Silurian rocks about 32 km north-northeast of Orbost first noted by Stirling (1888a) and formerly referred to as the Sardine Beds (Talent et al. 1975; Taylor 1984), was regarded as consisting of two units, the Sardine Conglomerate (a submarine fan deposit) overlain by Wibenduck Limestone (VandenBerg 1988; VandenBerg et al. 1992). There are no exposures of the contacts between the Wibenduck Limestone and adjacent tracts of conglomeratic Sardine Conglomerate *sensu stricto* nor of the former with the Warbisco Shale (Ordovician), though it is probable that the latter is a fault boundary. We interpret the "Wibenduck Limestone" to consist of clasts of various carbonate and calcareous lithologies, lithified before cannibalisation and incorporation into the fan deposit. We thus regard it as a limestone-charged debris flow at the top of the spectacular Sardine Conglomerate fan deposit (Talent et al. 2003a) rather than as a discrete formation.

Conodonts from the "Wibenduck Limestone", reported (VandenBerg 1988: 131) but not documented previously, were reviewed by Talent et al. (2003a). They concluded that the fauna is consistent with a generalized Ludlow age and opined that the fan may be interpreted as a reflection of Late Silurian synorogenic sedimentation. Conodonts recovered in this study generally indicate a mid to late Ludlow age (probably latest Gorstian–earliest Ludfordian) consistent with the cannibalisation and redeposition scenario suggested here.

The conodonts obtained from acid-leaching limestone float and from samples from a tiny quarry beside the Scanlon Creek Track (type locality of the "Wibenduck Limestone", VandenBerg et al. 1992: 27; see Appendix, loc. 5) have a high breakage ratio, consistent with appreciable transport of much of the fauna prior to lithification, somewhere upslope — from wherever the clasts may have been derived. The age indicated by the "Wibenduck Limestone" could thus be older, even appreciably older, than the age of accumulation of the Sardine Conglomerate fan deposit. We suggest the latter to be an analogue of the Sharpeningstone Conglomerate of the Yass district of southern New South Wales, a unit closely connected chronologically with the onset of the Bowning Orogeny — cf. conodont data for the Elmside Formation and Sharpeningstone Conglomerate in Link & Druce (1972).

TECTONIC IMPLICATIONS

A "package" of events — deformation, regional metamorphism, and plutonism — during latest Ordovician–Early or mid-Silurian times (the traditional view), or Late Silurian in eastern Victoria (VandenBerg et al., e.g. 1998a, 2000) — has long been assumed to have impacted more dramatically on the geological evolution of eastern Australia than any other "package" of events during the last 500 million years. This has long been referred to as the Benambran Orogeny (e.g. Browne 1947; Packham 1969; Scheibner 1998; Reed 2001). During the last decade, an alternative view has developed, that Silurian and Devonian orogenic events, including the "Benambran" events, were not clustered into discrete time-slices — see debate: Gray & Foster 1997, 1998, 1999; Gray et al. 1997; Foster et al. 1999, 2000; Foster & Gray 2000; VandenBerg 1999; VandenBerg et al. 2000; Collins & Hobbs 2001). That there can be such divergent opinions underlines the poor knowledge of most major events (or sub-events) during that interval, especially as regards time-control on the sedimentary sequences reflecting events "set in train" by deformation.

In a recent survey of stratigraphic alignments for the Silurian of Australia, Talent et al. (2003a) re-affirmed that there was indeed a hiatus equating with much or all of early and middle Llandovery time in eastern Australia and, in most cases, a striking angular unconformity associated with a profound contrast in tectonic style between juxtaposed units. In most areas, such as in the vicinity of Canberra, Quidong, Bungonia and the Broken River region of northeast Queensland, the dramatic contrast in deformation between the juxtaposed units implies greater tectonic activity than occurred during the remainder of Silurian and Devonian time. However, during a recent debate on diastrophism in the Lachlan Fold Belt of south-eastern Australia (see references above), contrasting scenarios were presented for the entire Late Ordovician–Devonian interval (including the "Benambran" time-slice): west–east continuous (non-episodic) diastrophism connected with essentially continuous subduction-induced deformation ("Lachlan Orogeny") *versus* discrete/episodic events. Disagreement included the significance regarding spatial and temporal variation in deformation that might be inferred from Ar–Ar dates on white micas — argued to reflect migration of the cleavage front in the "deforming sedimentary pile". The Ar–Ar database is, however, sparse and has been obtained mostly from the western part of the Lachlan Fold Belt. The eastern part of the Lachlan

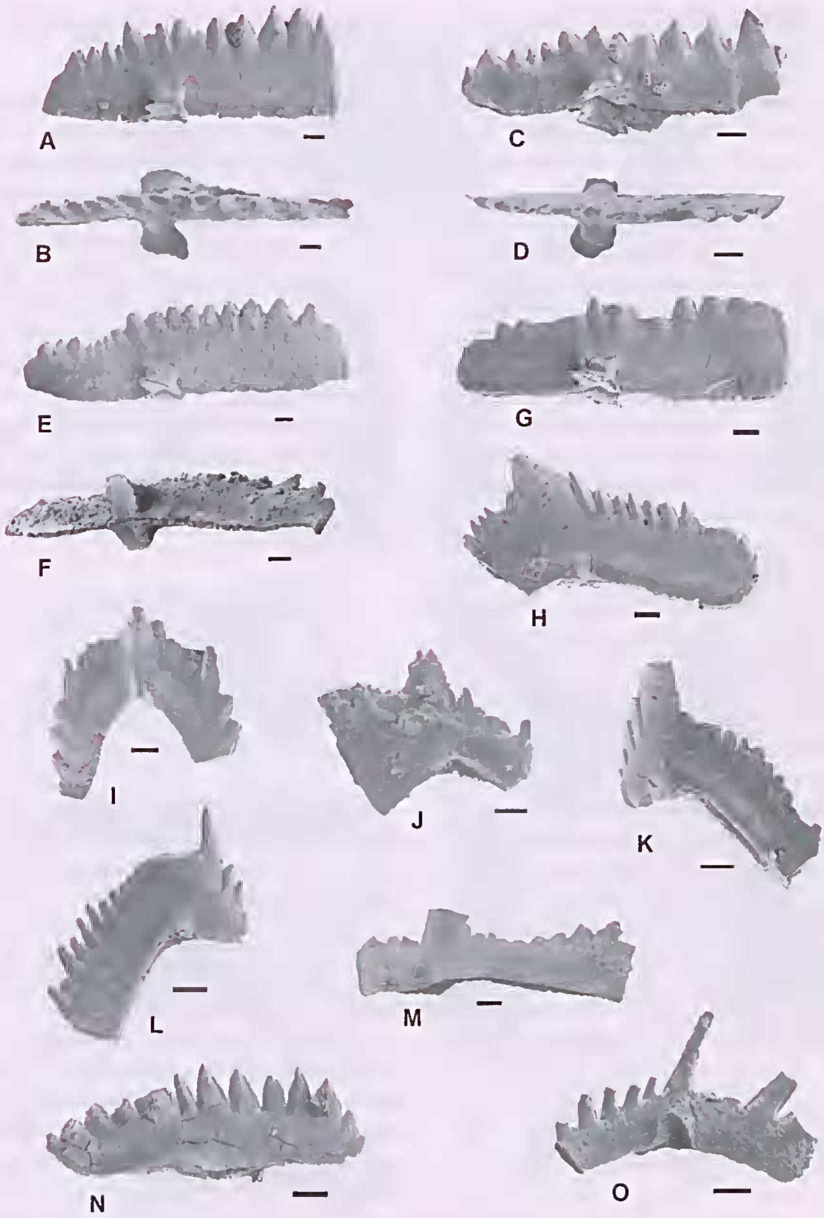


Fig. 5. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (east) flank of the Mitta Mitta River, eastern Victoria. The location is indicated on Fig. 2 and determinations are presented in Table 1. All specimens are housed in the Australian Museum, Sydney, with prefix AMF.
A-I, *Ozarkodina cadiaensis* Bischoff, 1986. A, B. Pa element, 3.2m, inner lateral and upper views respectively of AMF 125116. C, D. Pa element, inner lateral and upper views respectively of AMF 125117, 27.4m. E, F. Pa element, inner lateral and lower views respectively of AMF 125118, 15.7m. G. Pa element, outer lateral view of AMF 125119, 22.5m. H. Pb element (incomplete), lateral view of AMF 125120, 22.5m. I. Sa element, inner lateral view of AMF 125121, 27.4m. J. Sb element, inner lateral view of AMF 125122, 15.6m. K. M element, inner lateral view of AMF 125123, 15.6m. L. M element, inner lateral view of AMF 125124, 15.6m. M-O. *Ozarkodina australensis* Bischoff, 1986. M. Sc element of AMF 125125, 20.5m. N. Pa element, inner lateral view of AMF 125126, 20.5m. O. Sb element of AMF 125127, 23.5m.

Fold Belt, including the areas that form the foci of the present report, has large tracts that appear to be less amenable to regional Ar–Ar dating of metamorphic micas, so palaeontologic data in conjunction with sedimentary and tectonic data retain importance in the discussion for eastern Victoria and south-eastern New South Wales.

We suggest that whatever tectonic scenario is put forward should not ignore the evidence of well-dated major unconformities reflecting intense deformation, or biostratigraphic data (unless derived from demonstrably allochthonous material). If as we suggest, some of the Enano and Wombat Group carbonate intervals are autochthonous and pre-Ludlow, then the tectonic scenario should be made to accommodate these data. Our view is the traditional view: that a substantial "package" of events — deformation, regional metamorphism, and plutonism — indeed took place during the Llandovery, especially early- and mid-Llandovery times, but an integrated story of what happened (tectonic, igneous and sedimentary) during the Silurian has still to be spelled out with good chronologic underpinning. The picture is more complex than may at first appear. Some of the sequences, long asserted to be Late Silurian (e.g. by Walley et al. 1990), in fact fall within the latest Ordovician–Llandovery/earliest Wenlock interval. We are aware that linkages between deformation, uplift, erosion and derived sedimentation may be complex, with the possibility that unconformity-bound sedimentary packages resulting from erosion and sedimentation "set in motion" by a specific cycle of deformation could post-date the onset of the deformation by as much as "several million years" (Foster et al. 2000: 816) — and be diachronous. Clearly, there is a long way to go before the Benambran events have been adequately deciphered and compelling linkages established.

TAXONOMIC NOTES

Ozarkodina australensis Bischoff, 1986

Fig. 5, M–O, Fig. 6, H, K, L, O, P, Fig. 7, O.

Ozarkodina australensis Bischoff 1986: 126, pl. 22, figs 1–21. – Simpson & Talent 1995: pl. 7, figs 2–22.

Ozarkodina excavata eosilurica Bischoff 1986: 137, pl. 25, figs 10–34.

Ozarkodina sp. C Armstrong 1990: 96, pl. 14, figs 17–18, 20.

Remarks. Bischoff (1986) obtained several *Ozarkodina* specimens from mid-western New South Wales from earliest and pre-Wenlock strata, separated these into different taxa, and suggested an evolutionary relationship with the younger *Ozarkodina excavata excavata*. Simpson & Talent (1995: 140) placed two of these, *O. australensis* and *O. excavata eosilurica*, in synonymy. Closely similar Pa elements with short blades and straight to slightly concave basal margins were recovered from the Mitta Mitta Formation. Whilst these elements have a morphology superficially resembling the highly variable *O. excavata excavata*, numbers are too low to shed any further light on evolutionary relationships, so the taxonomy of Simpson & Talent (1995) is retained.

Ozarkodina cadiaensis Bischoff, 1986

Fig. 5, A–I, Fig. 7, H, L, M.

Ozarkodina cadiaensis Bischoff 1986: 132, pl. 24, figs 11–27, 30. – Simpson & Talent 1995: 142, pl. 7, figs 23–25.

Remarks. This taxon has a distinctive Pa element characterised by the V-shaped separation between the cusp and adjacent denticle, decline in denticle height from anterior to posterior, and the small rounded basal cavity with pinched basal margins. All elements of *Ozarkodina cadiaensis* are characterised by small closely packed denticulation and restricted basal cavities.

Bischoff (1986: 133–134) provided descriptions of the Pa, Pb, and M elements. In the symmetry transition series he recovered only the Sc element. In this study we recovered all of the above elements and identified distinctive Sa and Sb elements. Brief descriptions are given below.

Sa element: Alate element with minute basal cavity, high lateral processes with concave lower margins separated by an acute angle. Proximal denticles are erect, distal denticles inclined outwards giving an overall "fan-like" appearance.

Sb element: Digyrate element with small rounded basal cavity, one high lateral process and one low lateral process both with small closely packed denticulation abutting prominent cusp.

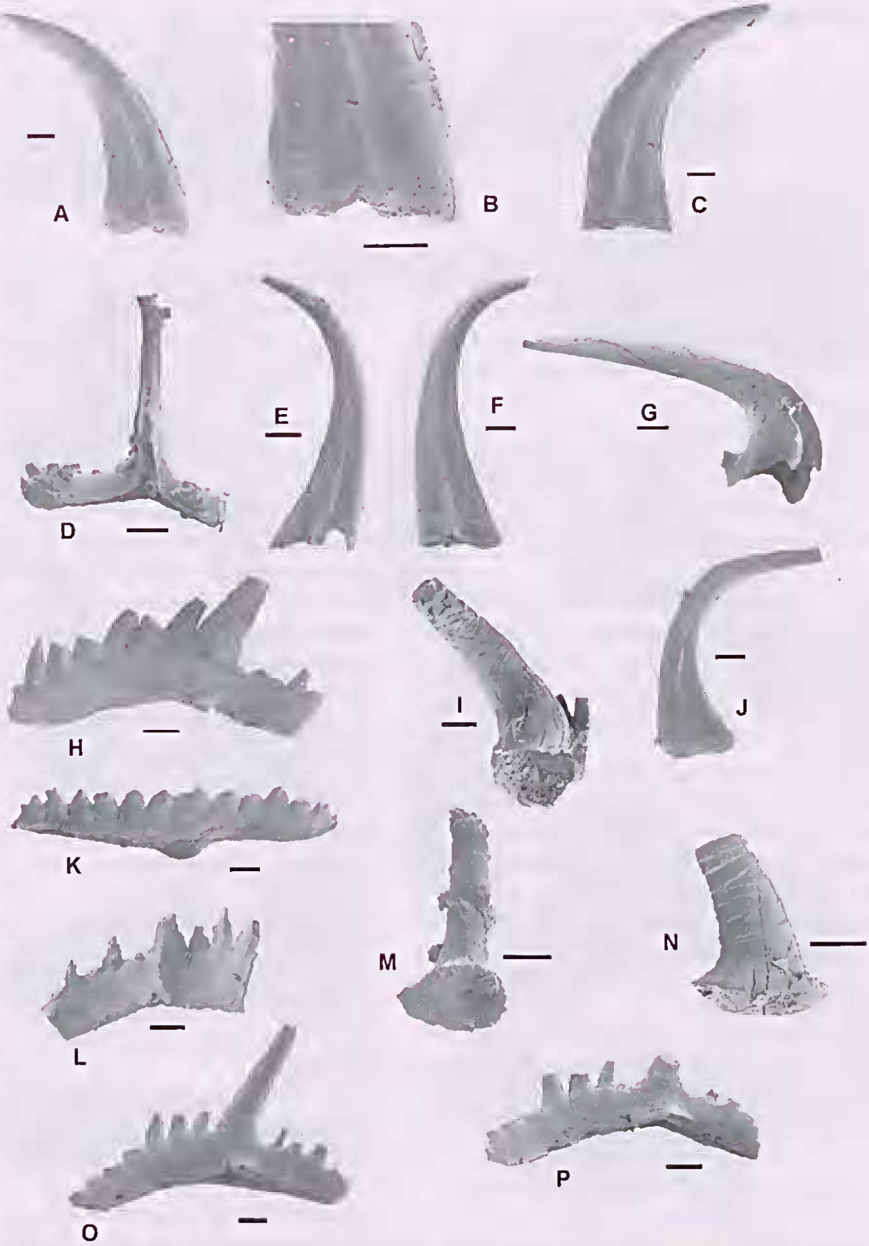


Fig. 6. Early Silurian (Llandovery) conodonts from stratigraphic section through the "Lower Mitta" limestone body on the right (east) flank of the Mitta Mitta River, eastern Victoria.
A-C *Panderodus* sp. A, B lateral view and enlargement respectively of AMF 125128, 22.5m. C. lateral view of AMF 125129, 22.5m. D. *Ozarkodina excavata excavata* (Branson & Mehl 1933) Sa element, inner lateral view of AMF 125130, 19.3m. E, F. *Panderodus unicostatus* (Branson & Mehl 1933) lateral views of AMF 125131, 3.2m and of AMF 125132, 19.3 m respectively. G, I, M, N. *Distomodus staurognathoides* (Walliser 1964). G. Sb element, lateral view of AMF 125133, 22.5m. I. Sc element (fragmentary), posterior view of AMF 125134, 19.3m. M-N Undifferentiated cones, 3.2.m, AMF 125135 and AMF 125136, respectively. H, K, L, O, P. *Ozarkodina australensis* Bischoff, 1986. H. Pb element, inner lateral view of AMF 125137, 18.3m. K. Pa element, upper view of AMF 125138, 3.2m. L. Sb element, inner lateral view of AMF 125139. O, P. Pb elements, inner lateral views of AMF 125140 and of AMF 125141, respectively, 3.2m. J. *Panderodus recurvatus* (Rhodes 1953) lateral view of AMF 125142, 15.6m.

Ozarkodina aff. **cadiaensis** Bischoff, 1986
Fig. 7, A–E.

Description. Pa element: Carminate element with a short posterior process and long anterior process. Lower margins of processes are straight, meeting at less than 180 degrees, giving a concave appearance to the lower margin. Small rounded basal cavity located in posterior half of element beneath, and slightly anterior to prominent cusp. Posterior process is low with two or three small proximal denticles and one larger distal denticle. Anterior process relatively high with seven or eight large denticles of generally equivalent size.

?Pb element: Angulate element with prominent cusp and large denticles (element incomplete).

?Sa element: Alate element with prominent cusp and thick processes with narrow ledges beneath subdued denticulation (element incomplete).

Remarks. Three different element types (two of which are represented only by fragmentary specimens) were recovered from the same sample from the southeastern end of the Quart Pot limestone. Morphological similarities enable them to be grouped tentatively in the one taxon.

The Pa element strongly resembles *Ozarkodina cadiaensis*, in particular with respect to the size and structure of the basal cavity. The main differences are the subdued denticulation on the posterior process, the more prominent cusp and the less obvious development of a V-shaped separation between denticles above the basal cavity. More specimens are required to establish whether this form is aberrant but within the range of intraspecific variation for *O. cadiaensis*, or whether it represents a separate taxon. Without intermediate morphologies it is not possible to imply this form is related in some way to *O. cadiaensis*; it is therefore left in open nomenclature.

Ozarkodina excavata excavata
(Branson & Mehl, 1933)
Fig. 6, D, Fig. 8, C, D, F.

For synonymy see Simpson & Talent (1995) and add the following:

Aspelundia fluegeli (Walliser): Percival 1998: Fig. 3.6.

Ozarkodina excavata (Branson & Mehl): Miller 1995: pl. 1, fig. 8.

Ozarkodina excavata excavata (Branson & Mehl) – Barca et al 1992: pl. 10, figs 3–5: – Sloan et al. 1995: pl. 12, figs 15, 18: – Simpson & Talent 1995: 147–153. pl. 8, figs 16–25, pl. 9, figs 1–24: – Colquhoun 1995: pl. 1, fig. 16: – Furey-Greig 1995: pl. 1, figs 12–14: – Carey & Bolger 1995: 79–81, Fig. 3G–H: – Serpagli et al. 1998: pl. 1.2.1, figs 4–5; pl. 1.2.2, fig. 1: – Corradini et al. 1998: pl. 1.3.1, fig. 1: – Ferretti et al. 1998: pl. 2.2.1, fig. 1: – Percival 1998: Fig. 4.2: – Talent & Mawson 1999: pl. 5, figs 1, 3–4; pl. 5, figs 1–4; pl. 6, figs 19–22; pl. 9, figs 8–9: – Cockle 1999: 120, pl. 3, figs 1–14: – Talent et al. 2003a: pl. 2, figs R–S, pl. 3, fig. S, pl. 4, fig. K.

Remarks. This is one of the most numerically abundant, highly variable and widely recognised conodont taxa recovered from Silurian strata. Simpson & Talent (1995: 147–153) discuss this subspecies and its differentiation from the older and probably closely related *Ozarkodina australensis*. The fauna from this study add no new insights to the question of the relationship between *O. excavata excavata* and *O. australensis*. It would be unwise to preclude the possibility that better faunas from more continuous sequences may indicate a closer phylogenetic relationship than inferred herein. Until this time the taxonomy and interpretations of Simpson & Talent (1995) are retained.

Ozarkodina martinssoni auriformis
Simpson, 2003
Fig. 8, A–B.

For synonymy see Simpson (2003) and add the following:

Ozarkodina martinssoni auriformis Simpson 2003 – Talent et al. 2003a: pl. 2, fig T.

Remarks. The distinctive Pa element of this taxon is readily separated from other Pa elements in this study such as *Ozarkodina cadiaensis* on the following morphological criteria. *O. martinssoni auriformis* has a distinctive two-level height of denticle development, and denticle-size is relatively even on both the anterior and posterior processes. *O. cadiaensis* has an undulose development of denticles in lateral outline. The basal cavities of *O. martinssoni auriformis* and *O. cadiaensis* are similar in having pinched margins close to the blade. The basal cavity

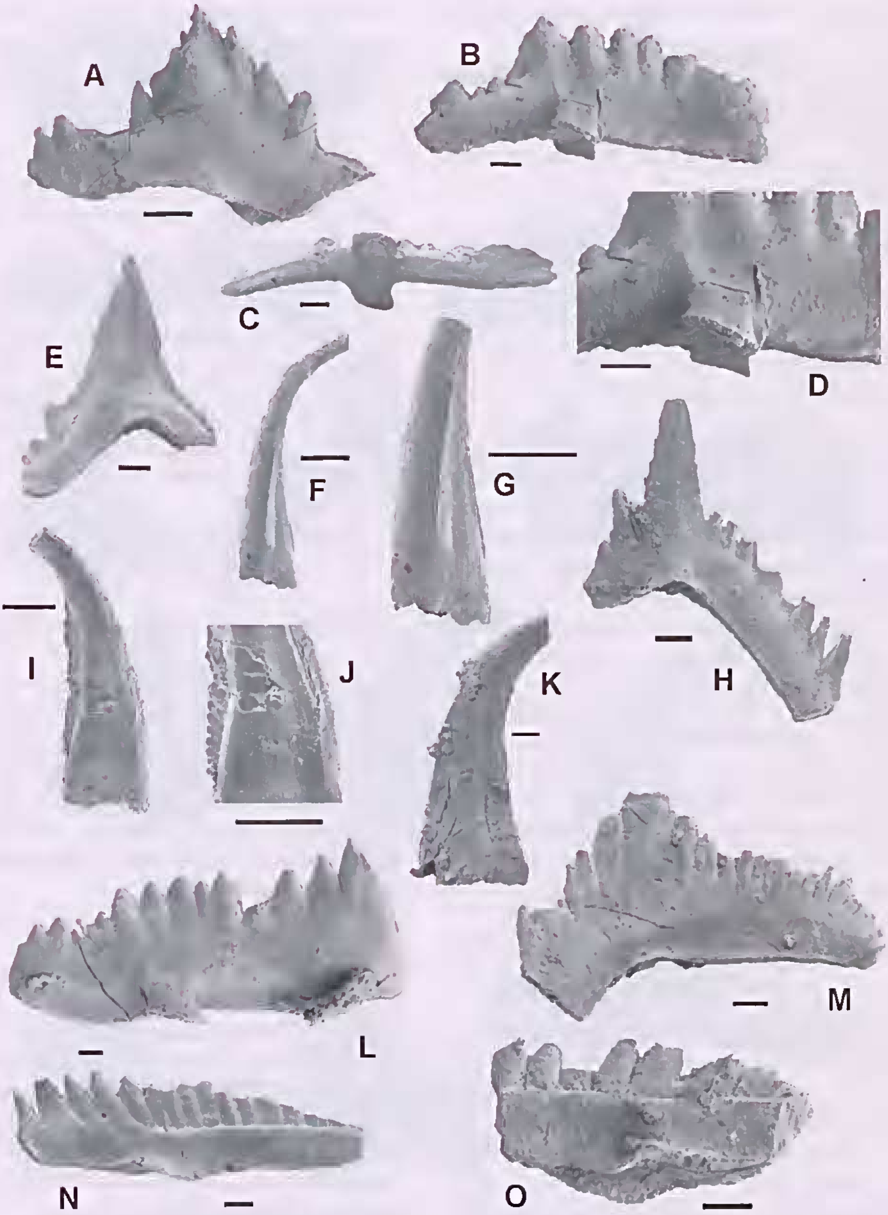


Fig. 7. Early Silurian (Llandovery) conodonts from stratigraphic section at Brammall Bluff on the Gibbo River (locality 2; = 'Hairpin limestone' of VandenBerg et al. 1998a), and from a spot sample at locality 3, at SE end of Quart Pot limestone tract. Locations are indicated on Fig. 2.

A-E. *Ozarkodina* cf. *cadiaensis* Bischoff 1986. A. Pb element, lateral view of AMF 125143, Loc. 3. B-D. Pa element, lateral view, lower view and enlargement of basal cavity respectively of AMF 125144, Loc. 3. E. Sa element, lateral view of AMF 125145, loc. 3. F, G. *Panderodus unicostatus* (Branson & Mehl 1933) lateral view and enlargement of AMF 125146, Loc. 2, 0.1m. H. *Ozarkodina cadiaensis* Bischoff 1986 M element, inner lateral view of AMF 125147, Loc. 2, 0.1m. I, J. *Pseudobelodella silurica* Armstrong 1990 aq element lateral view and enlargement respectively of AMF 125148, Loc. 2, 5.7m. K. *Panderodus* sp., lateral view of AMF 125149, Loc. 2, 5.7m. L, M. *Ozarkodina cadiaensis* Bischoff 1986. L. Pa element, inner lateral view of AMF 125150, Loc. 2, 0.1m. M. Pb element, lateral view of AMF 125151, Loc. 2, 0.1m. N, O *Ozarkodina australensis* Bischoff, 1986. Pa elements, lateral views of AMF 125152 and AMF 125153, respectively, Loc. 2, 0.1m.

of the former, however, is relatively larger than the latter.

Simpson (2003) provided the description and reconstruction of this taxon. It is geographically widespread and restricted to the interval from the Ludlow *siluricus* Zone through to the earliest Devonian *woschmidti* Zone.

Ozarkodina remscheidensis eosteinhornensis (Walliser, 1964)

Fig. 8, G.

For synonymy see Simpson & Talent (1995), supplemented by Mawson et al. (2003).

Remarks. This taxon has been discussed by Simpson & Talent (1995), *inter alia*, and additional interpretations concerning the phylogeny of the broader group were given by Mawson et al. (2003). A single Pa element was recovered from the Pyle's limestone unit. Despite one larger denticle on the anterior process, this poorly preserved element is characterised by a row of denticles of approximately uniform height, each being relatively perpendicular to the blade, and the typical widely flared basal cavity. It therefore readily fits within the variation of the populations of the subspecies from Cellon as illustrated by Walliser (1964, Pl. 20, figs 7, 8, 12–16, 19–25) and revised by Klapper & Murphy (1974). This is a broader view of the taxon than utilised by Jeppsson (1989).

Distomodus staurognathoides (Walliser, 1964)

Fig. 6, G, I, M–N.

For synonymy see Simpson (1999: 189) and add the following:

Distomodus staurognathoides (Walliser) – Cockle 1999: 120, pl. 1., fig. 18. – Talent & Mawson 1999: pl. 3, figs 3–4, 9–15: – Rickards et al. 2001: Fig. 2, h–l: – Farrell 2002: Fig. 4, D–F, H, I, K: – Zhang & Barnes 2002: 13–15, Fig. 14.1–14.7.

Remarks. A single Sc element was obtained in this study. Although the ramiform complex of the genus *Distomodus* shows similarities across species, particularly in the symmetry transition series, we consider this element most probably represents *D. staurognathoides* because of the age of the interval. It is almost identical in morphology to that illustrated by Rickards et al. (2001: Fig. 4i.) from the *amorphognathoides* Zone, the latter was recovered with the distinctive platform element.

?Icriodus sp. a Simpson

Fig. 8E.

?*Icriodus* sp. n. A Simpson 1998: 160, pl. 3, figs 12–19.

Remarks. This single element bears strong similarity to Late Silurian elements recovered from the Jack Formation in north Queensland (Simpson 1998). Whilst the element has the typical triangular basal structure typical of Sa elements, this example is slightly asymmetrical and may possibly represent an Sa/Sb transitional form.

Pseudobelodella silurica Armstrong, 1990

Fig. 7, I–J.

For synonymy see Simpson & Talent (1995: 176).

Remarks. The single element is erect with numerous fused apically inclined denticles. It has a close resemblance to the aq element of this taxon. Despite the fact that Armstrong (1990) differentiated this genus from *Belodella* by the presence of the heeled sym p element, the morphology of the single aq element recovered in this study allows identification with some confidence.

Panderodus ?n. sp.

Fig. 8J.

Remarks. The single element described above has a number of distinctive features not typically noted in populations of *Panderodus*. It may therefore represent a new species. It is illustrated and kept in open nomenclature for comparative purposes. Other *Panderodus* elements obtained in this study have not been investigated in detail.

APPENDIX: NOTES ON SAMPLED LOCALITIES

1. This, the most productive for conodonts of the limestone occurrences sampled, outcrops boldly on both flanks of the Mitta Mitta River about 260–320 m upstream from its junction with Wombat Creek (Whitelaw 1954: fig. 2^{E}). It was interpreted

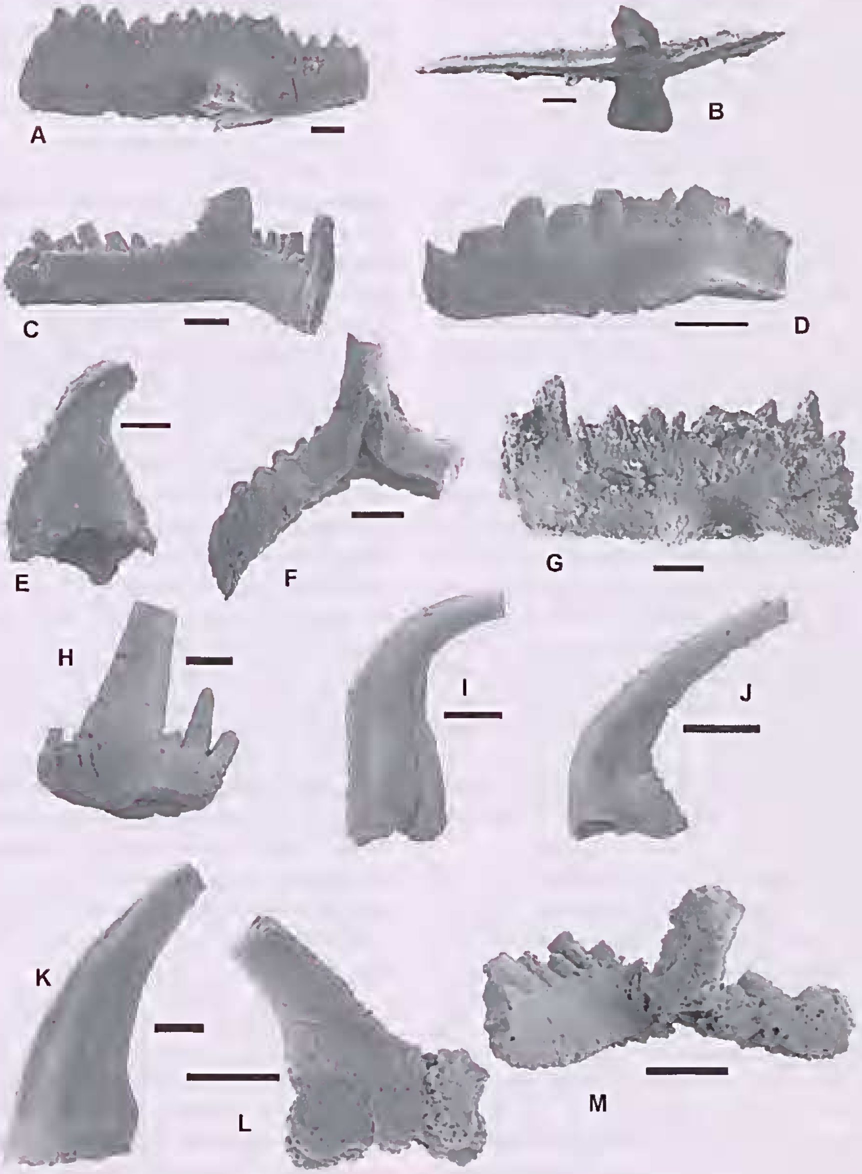


Fig. 8. Late Silurian (late Ludlow to mid-Přidolí) conodonts from Pyle's limestone deposit, 4.5 km north-northeast of Benambra, and Late Silurian conodonts from limestone clasts, "Wibenduck Limestone", Martins Creek-Sardine Creek Saddle, eastern Victoria (for localities see Appendix, Fig. 1, and VandenBerg et al., 1998b, 1992).
A-B. *Ozarkodina martinsoni auriformis* Simpson 2003, Pa element, lateral and lower view respectively of AMF 125154, Loc. 5. C-D. *Ozarkodina excavata excavata* (Branson & Mehl 1933). C. Sc element, inner lateral view of AMF 125155, Loc. 5. D. Pa element, outer lateral view of AMF 125156, Loc. 5. E. ?*Icriodus* sp. a Simpson 1998, Sa/Sb element, posterior view of AMF 125157, Loc. 5. F. *Ozarkodina excavata excavata* (Branson & Mehl 1933). Sa element (incomplete), inner lateral view of AMF 125158, Loc. 5. G. *Ozarkodina remscheidensis eosteinhornensis* (Walliser 1964). Pa element, lateral view of AMF 125159, Loc. 4. H. *Ozarkodina excavata excavata* (Branson & Mehl 1933) fragmentary ?Sb element, inner lateral view of AMF 125160, Loc. 4. I. *Panderodus* sp., lateral view of AMF 125161, Loc. 4. J. *Panderodus* ?n. sp., lateral view of AMF 125162, Loc. 4. K. *Panderodus* sp., lateral view of AMF 125163, Loc. 4. L. Indeterminate fragment, AMF 125164, Loc. 4. M. *Ozarkodina* sp., fragmentary Sb element, AMF 125165, Loc. 4.

(VandenBerg et al. 1998b) as two bodies, one within the Toaks Creek Conglomerate, the other at the boundary between the Toaks Creek Conglomerate and the overlying Gibbo River Siltstone. We prefer Whitelaw's (1954: 26) interpretation that these are outcrops of the same limestone body on opposite sides of the Mitta Mitta River. Our sampled section commenced at the base of the limestone (= Whitelaw 1954, Fig. 2^E; = 'Lower Mitta limestone' of VandenBerg et al. 1998a = base of the Gibbo River Siltstone) on the east flank of the Mitta Mitta River arm of Dartmouth Dam at grid reference 5589_5,59318_0 on Benambra 1:50,000 sheet 8424-3.

2. Sampled section (11 samples) through Brammall Bluff (Whitelaw 1954, Fig. 3^B; = 'Hairpin limestone' of VandenBerg et al. 1998a); interpreted by VandenBerg et al. (1998a) as being in the Undowah Siltstone on the north flank of the Gibbo River commencing at grid reference 5607_{96},59314_{63} on Benambra 1:50,000 sheet 8424-3. The start of the sampled section is 75 m (across strike) above the base of an interval of generally massive, yellow-buff-weathering dolomitic limestone or dolomite. The section extends through 37 m of well-bedded siltstones with slatey carbonates (often iron-rich), thin-bedded rather bioclastic limestones and nodular limestones (subordinate to siltstones), and is followed by a further 25 m with buff- to yellow-weathering dolomitic olistoliths (largest c. 5 m) exhumed from upslope.

3. Spot sample from the southeast end of 'Quart Pot limestone' of VandenBerg et al. (1998a) (= Whitelaw 1954, Fig. 2^D) at grid reference 5568_{45},59326_3 on Benambra 1:50,000 sheet 8424-3. Repeated sampling of the 'Quart Pot limestone' (Whitelaw 1954, figs. 2^C and 2^D) at grid reference 5565_5,59327_5 (limestone with pentamerids) and 5565_3,59327_4, and the nearby 'Toak's Gap limestone' in the vicinity of 5540,5935_7, all on Dart 1:50,000 sheet 8424-4, failed to produce conodonts. In both cases contacts with the underlying conglomerates and arenites and with the overlying mudstones are obscured by alluvials or soil.

4. Spot samples from Pyle's limestone deposit (Whitelaw 1954: fig. 3^D; Talent et al. 1975; Simpson & Talent 1995; VandenBerg et al. 1998a) at grid reference 5644_8,59141_0 on Benambra 1:50,000 sheet 8424-3 where there are poor exposures of metamorphosed calcareous siltstones and arenites with minor thin bands of limestone. This occurrence was interpreted (VandenBerg et al. 1998a: 104) as overlying Pinnak Sandstone (Early Ordovician).

5. Spot samples of "Wibenduck Limestone" from float and from a small quarry outcropping beside the Scanlon Creek Track on Bendoc 1:100,000 sheet 8623 at grid reference 394,557.

6. Samples from the 'Lower Gibbo limestone' (a body we agree with VandenBerg et al. 1998a, is an olistolith) at 5597_5,59317_5, from the 'Silver Flat limestone' in the vicinity of 5612,59308 (several samples), from the counterpart of the 'Lower Mitta limestone' of VandenBerg et al. (1998a; = Whitelaw 1954, Fig. 2^E) but on the west flank of the Mitta Mitta River arm of Dartmouth Dam, and from a sampled stratigraphic section through the 'Meanders 3 limestone' of VandenBerg et al. (1998a) in the vicinity of 5592,59292, all on Benambra 1:50,000 sheet 8424-3, also failed to produce conodonts.

7. A superbly exposed limestone and calcareous mudstone sequence (Whitelaw 1954: fig. 2^F) outcrops in a cliff on the right flank of the Mitta Mitta River about 3.6 km upstream from its junction with Wombat Creek. It may be as much as 1000 m stratigraphically higher in the Tongaro Siltstone than the 'Lower Mitta limestone', but the possibility of faulting (Fig. 3) between it and the 'Lower Mitta limestone' prevents accurate assessment of the intervening thickness. It too shows very gradual transition from massive through bedded limestone to calcareous mudstones — again a relationship we interpret as indicating a probably autochthonous sequence rather than an olistolith. Unfortunately this occurrence — with tabulate corals including halysitids (Chapman 1920) — has so far failed to produce conodonts.

ACKNOWLEDGEMENTS

We pay tribute to Fons VandenBerg and co-workers for the major advances they have made in understanding the geology of vast areas of the most rugged parts of eastern Victoria, elegantly summarised in VandenBerg et al. (2000). We are grateful to Fons for having generously made available a copy of a manuscript embodying his views on the age, depositional environments, and tectonic setting of the Silurian limestones of eastern Victoria. We are also grateful to John Webb who gave us a collection of conodonts from the "Wibenduck Limestone", to Anita Harris of the U.S. Geological Survey for making available to us a colour-standard set of conodonts for making our CAI determinations, and to Greg Edgecombe, Lennart Jeppsson and Ian

Percival for attentively reading and making helpful comments on our manuscript. The drafting is by our friend Dean Oliver.

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